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TECHNIQUES FOR PACKAGING AND ENCAPSULATING COMPONENTS OF DIAGNOSTIC PLASMA MEASUREMENT DEVICES

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TECHNIQUES FOR PACKAGING AND ENCAPSULATING COMPONENTS OF DIAGNOSTIC PLASMA MEASUREMENT DEVICES

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to the field of plasma processing, and more particularly to devices for in-situ measurement of plasma properties within a plasma processing system.

Brief Description of the Prior Art

With the emergence of wireless, wafer-based plasma measurement probes, it has become possible to obtain virtually noninvasive, in-situ measurements of actual physical and electrical properties of a plasma within an operational plasma processing environment. A wireless diagnostic plasma probe may comprise sensor devices disposed upon a substrate body that is comparable in physical structure and dimensions to a standard process workpiece, as for example a semiconductor wafer. An onboard power source may be provided, as well as electronic components for collecting, processing and storing data received from the sensors. A wireless communication transceiver receives and transmits the sensor data outside of the plasma processing environment for further processing and analysis. Diagnostic sensors may include devices that measure thermal, optical, and electromagnetic properties of the process environment, and ideally include sensors such as dual floating Langmuir probes that can measure physical and electrical properties of the plasma itself without disturbing the properties being measured. Further description of the operation and utility of exemplary plasma wafer probe devices is presented in U.S. Patent Application No. 10/194,526, assigned to the assignee of the instant application.

To obtain in-situ measurements within a plasma process, a wafer-based plasma probe must be resilient to the harsh environment of a plasma processing system, which may include conditions such as excessive heat, corrosive chemicals, bombardment by high energy ions, and high levels of electromagnetic and other radiative noise.

International Patent Appl. No. WO 02/17030 describes one approach for isolating and shielding electronic components of a wafer-based plasma probe from process conditions. A cavity is provided in the wafer substrate for placement of the information processor, internal communicator, and power source of the device. An electromagnetic shield is placed around the components, and a substrate cover is disposed so as to cover the cavity for protection of the electronic components within. Hermetic sealing of the cover to the substrate is described to prevent the escape of contaminants from the cavity into the process environment.

As an alternative to trenching a protective cavity into the silicon wafer, electronic components of a diagnostic plasma probe may be deployed upon the substrate within a protective package having insulated electrical connections, as described for example in U.S. Appl. No. 10/194,526. For wafer diagnostic probes to be cost effective for high-volume commercial applications, such as in the manufacture of semiconductor devices, it should be possible to mass produce probes for use in large quantities as consumable articles. To this end, a diagnostic probe having a simplified and standardized design with minimal part count would be advantageous. A plasma probe engineered for enhanced manufacturability must nevertheless continue to have acceptable performance and operational life in the harsh process environment, while adhering to structural and dimentional constraints imposed by the workpiece mounting and transfer mechanisms of the process apparatus. Materials used in the construction of a diagnostic probe must also be compatible with and tolerant of the processing environment such that the use of the plasma probe does not result in either physical or chemical contamination of the processing chamber, or of material subsequently processed in the processing chamber.

SUMMARY OF THE INVENTION

This invention provides techniques for the configuration, packaging, and encapsulation of components of plasma measurement probe devices. A measurement probe of the invention generally comprises a primary substrate with sensor devices disposed about the surface of the probe. An electronics module contains electronic components or other elements of the diagnostic probe that require isolation and shielding from process conditions. The electronics module is disposed upon the probe substrate and electrically connected to the remote sensor devices through one or more electrical interconnection layers disposed upon the substrate.

In one embodiment of the invention, an electronics module comprises electronic components including one or more of a microprocessor, data storage (RAM), ROM, multiplexer, A/D and D/A converters. An electrostatic shield is incorporated into the electronics module, which is prefabricated and hermetically sealed as a unit. Using a pliable adhesive, the electronics module is mounted to the surface of a wafer-based diagnostic device. Because the electronics module of the embodiment is hermetically sealed, no further sealing or encapsulation of the electronic components is required.

In one embodiment of the invention, the electronics module is electrically connected to the remote sensors and other components of the measurement probe device using flexible wirebond connections. To protect the wirebonds from ionic or chemical attack, an encapsulant is applied over the wires and bond points. In other embodiments, the electrical connections are made by direct bonding of the electronics module to an electrical interconnect layer of the probe device disposed upon the primary substrate. The electronics module may be directly bonded as a hermetically sealed unit, or alternatively may be bonded without a sealed housing and then covered with a high purity encapsulant.

Further integration is accomplished in certain embodiments of the invention by fabricating the electronics module directly on the wafer substrate, or by incorporating functions of discrete electronic components into one or more Application Specific Integrated Circuit (ASIC) devices. An electronics module comprised of one or more ASIC devices is directly bonded to an electrical interconnect layer of a probe device of

the invention and encapsulated. Electrostatic shielding is provided by a Faraday cage in the form of a sealed housing, for example, or alternatively by a thin film electrostatic coating applied in addition to the encapsulant layer.

By integrating and modularizing the electronic components of a sensor probe, the invention serves to reduce part count, simplify fabrication and increase function and reliability of the completed sensor device. As a result, the sensor probe design may be optimized for cost effective production techniques while ensuring mechanical, chemical, and thermal compatibility with the wafer or other carrying substrate and the environment to which it is exposed. The use of hermetic housings and/or augmenting encapsulants to protect onboard electronics eliminates the risk of attack from reactive chemicals present in harsh processing environments, and appropriate selection of adhesive and encapsulant materials provides stress relief during thermal cycling. The hermetic housing and/or encapsulant also provide protection to the plasma processing chamber from potential contamination, chemical or otherwise, that may originate from the electronics circuit or components themselves. Incorporation of electrostatic shielding in the electronics module provides noise immunity to the circuit and facilitates package construction. The configuration, packaging, and encapsulation techniques of the invention thus provide for enhanced durability and manufacturability of diagnostic plasma probes for operation in increasingly harsh process environments.

When configured upon a silicon wafer primary substrate, diagnostic probes of the invention are ideally suited for measuring in-situ plasma properties in semiconductor fabrication processes. The device and technology are also suitable for use in other plasma applications and process environments. For example, the described electronics package and accompanying sensors of the invention may be mounted upon typical substrates employed in the production of flat panel displays, architectural glass, storage media, and the like. These substrates may include but are not limited to all semiconductor substrates (silicon, gallium arsenide, germanium or others), as well as micro machine substrates, quartz, Pyrex and polymeric substrates.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates an example of a plasma processing system in which sensor probes of the invention may be utilized.

Figure 2 illustrates a wafer-based plasma probe with an electronics module in accordance with one embodiment of the invention.

Figure 3 illustrates a wafer-based plasma probe having a directly bonded electronics module in accordance with another embodiment of the invention.

Figure 4 illustrates a wafer-based plasma probe having an encapsulated electronics module in accordance with another embodiment of the invention.

Figure 5 illustrates a wafer-based plasma probe having an electronics module fabricated onto the substrate of the probe in accordance with another embodiment of the invention.

Figure 6 illustrates a wafer-based plasma probe having an electronics module comprising Application Specific Integrated Circuit devices in accordance with another embodiment of the invention.

DETAILED DESCRIPTION

Figure 1 illustrates one example of a plasma processing system in which sensor probes of the invention may be utilized. The plasma processing system 100 comprises a vacuum processing chamber 102, a pumping manifold 104, a plasma source electrode mounted to the top of the chamber 106, a gas delivery manifold or gas shroud 108, gas flow and power connections to the plasma source electrode 110, a wafer chuck 112 with clamp ring 114, or other provision for electrostatic clamping, RF power, fluid coolant, lifting pin, and helium backside-cooling services to the chuck 116, and a load lock transfer stage with mechanical robotics 118 to manipulate wafers into the chamber 102 and onto the chuck 112. A diagnostic probe 10 is comprised of a silicon wafer substrate that incorporates plasma sensor diagnostic circuitry and wireless communications and a stored power system. Preferably, the sensors are fabricated onto a semiconductor wafer such as a 200 mm or 300 mm diameter silicon wafer. Alternatively, the sensors may be fabricated onto any process work piece such as a ceramic, plastic, metal or glass work piece surface that can be introduced into the vacuum chamber. The probes are fabricated such that normal wafer transfer mechanics and robotics are utilized to move the probe wafers into and out of the plasma processing environment.

Plasma 120 is ignited to perform an etching or deposition process on the surface of the wafer, at which time the apparatus sensors and microprocessor are activated to collect data relating to surface or plasma properties in close proximity to the apparatus surface in real time. An on-board wireless transceiver system 122 is used to communicate data and instructions with a base station transceiver 124 outside the plasma processing system. The base station transceiver 124 allows for communication of data and instructions between the software of the external computer 126 and the probe 10 in real time. Alternatively, it is possible to have the probe collect information inside the process and then download data once it is removed from the process chamber.

Figure 2 illustrates a wafer-based plasma probe in accordance with one embodiment of the invention. It will be understood that in Figure 2, as well as in subsequent figures, the dimensions of certain illustrated features are not to scale but

exaggerated for clarity. Sensor probe 10 comprises a primary substrate 12 comprising a 200 mm or 300 mm silicon wafer of physical and electrical properties standard to typical semiconductor starting material. Probe 10 comprises one or more sensors 20 for measurement of plasma or surface properties. Although only one sensor is illustrated in Figure 2, it will be understood that sensor probes of the invention may comprise sensors of any type and number as may be desired to provide spatial and temporal characterization of various plasma properties, as described for example in U.S. Appl. No. 10/194,526. A dielectric layer 14, which may be comprised of a material such as silicon dioxide or other metal oxide or nitride, insulates silicon substrate 12 from an electrical interconnection layer 16. Interconnection layer 16 comprises conductive signal traces for electrical interconnection of sensors and electronic components of the probe, as may be created for example by techniques such as silk screening, contact photomasking, projection scanning or step and repeat projection lithography. A surface passivation layer 18, comprised for example of a dielectric metal oxide, nitride, or oxynitride, is provided for physical protection and electrical isolation of interconnection layer 16 from the plasma.

Disposed upon the surface of probe 10 is an electronics module 30. In Figure 2, the electronics module 30 is depicted as a hermetically sealed hybridized MultiChip Module (MCM) comprising a plurality of electronic components 40. Electronic components contained within electronics module 30 typically include at least one microprocessor and a wireless transceiver device, and may also include components such as data storage (RAM), ROM, multiplexer, A/D and D/A converters, batteries or other power elements, IR receiver, and filtering or other discrete components such as capacitors, inductors, and resistors. Electronic components are mounted upon a ceramic substrate 32, which preferably is composed of a material chosen to have thermal expansion characteristics compatible with those of primary substrate 12. A housing 34 covers electronic components 40 and is bonded to ceramic substrate 32 with a welded or soldered hermetic seal 38 to complete the electronics module enclosure. Housing 34 is constructed of a material such as quartz, anodized aluminum, or a polymeric material, as may be appropriate to the plasma environment of a particular application. A Faraday shield 36 is provided within or as part of the hermetically sealed housing 34 to protect

electronic components 40 against sources of external electrical or radiative noise. Using a stress relieving adhesive 39 to minimize mechanical and thermal stresses, electronics module 30 is bonded to an augmented portion of passivation layer 18.

A hermetically isolated electronics module such as that depicted in Figure 2 may be prefabricated using techniques well known in the art. U.S. Patent Nos. 5,786,548, 5,200,640, and 4,577,056, for example, describe construction of hermetically sealed surface mount electronics packages for semiconductor and electrical devices.

Contained within ceramic substrate 32 is an embedded electrical interconnect 42 for electrical connectivity among electronic components 40. Electrical interconnect 42 is terminated at a point outside the module housing allowing for electrical wirebonding 44 to connect the components of electronics module 30 to the remote sensors or other components of the probe 10 through interconnect layer 16. Compared with a rigid solder joint, for example, wirebond 44 provides a flexible connection that is more tolerant of stresses due to thermal expansion and contraction imposed by the plasma environment. To protect wirebond 44 from ionic or chemical attack, an encapsulant 46 is applied over the wires and bond points. Encapsulant 46 is a material such as Parylene or other high purity polymer or silicone, or any material of sufficient purity that is compatible with the chemical and thermal environment of the plasma and the thermal expansion cycles of the substrate.

Figure 3 illustrates an embodiment of the invention having an electronics module attached to the surface of a wafer-based plasma probe by direct electrical bonding. Probe 10 comprises silicon substrate 12, dielectric layer 14, and interconnection layer 16 overlaid by surface passivation 18. Exposed through passivation layer 18 are attachment points 50 of the interconnection layer 16. Electronics module 30 comprises electrical components 40 mounted upon ceramic substrate 32. Housing 34 with Faraday shield 36 is hermetically sealed 38 to ceramic substrate 32.

Substrate 32 of electronics module 30 has an embedded electrical interconnect with terminals 52 at locations corresponding to attachment points 50. Using for example a ball solder or wave solder technique, terminals 52 are directly bonded to attachment points 50. The direct bonding of terminals 52 to attachment points 50 connects electronics module 30 electrically as well as mechanically to the surface of probe 10.

Alternatively, mechanical bonding of the module may be supplemented with a pliable adhesive. To protect the direct bond junctions from chemical attack in the plasma environment, an underfill 54 is provided using a high purity material, such as an epoxy or other polymeric material, for encapsulation of the solder bonds.

In an alternative embodiment of the invention, the hermetic housing and underfill of the embodiment of Figure 3 are replaced with a direct encapsulation approach for protecting a directly bonded electronics module from the plasma environment. Referring to Figure 4, electronics module 30 comprises electrical components 40 mounted upon module substrate 32. Electrical interconnect terminals 52 of electronics module 30 are directly bonded to attachment points 50 of interconnect layer 16 of the wafer probe 10. A suitable, high purity encapsulant 60, such as Parylene or other high purity polymer or silicone, covers and encapsulates electronics module 30. Dam confinement ridges 62 are used to constrain the flow of the encapsulant and define "keep-out" regions as needed during cure. Electrostatic shielding of electronics module 30 is provided by depositing or plating a conductive layer 64 upon the encapsulant 60 thereby creating an integrated Faraday shield.

Figure 5 illustrates an embodiment of the invention in which the electronics module of a wafer-based plasma probe is fabricated directly onto the primary substrate of the probe. In this embodiment, interconnect circuitry required for the electronic components 40 of electronics module 30 is incorporated directly onto electrical interconnection layer 16 upon the primary substrate 12 using multilayer deposition, pattern and etch techniques common in the semiconductor industry. Direct electrical interfacing 50 may then be accomplished for electrical connection of the module electronics to the remote sensors of the probe. Housing 34 with Faraday shield 36 covers electrical components 40 and is hermetically sealed 38 to the surface of probe 10 Encapsulation 60 of electrical components 40 within the housing may be provided to augment protection of the components from the plasma environment.

Further integration of wafer probe electronics can be accomplished by incorporating functions derived from discrete components into one or more Application Specific Integrated Circuit (ASIC) devices. Figure 6 depicts an embodiment of the

invention comprising ASIC devices 70 constructed to perform the data storage, processing, and communication functions of the wafer probe device. ASIC devices 70 are directly bonded to attachment points 50 of interconnect layer 16 of the wafer probe 10 using for example solder bumps, wave soldering, or other appropriate "chip-on-wafer" technique. An encapsulation layer 60 is applied over ASIC devices 70 and a housing 34 with Faraday shield 36 and hermetic seals 38 covers electrical components completes the enclosure of electronics module 30 Alternatively, Faraday shielding may be provided by depositing or plating a conductive layer upon the encapsulant 60 as described in connection with the embodiment of Figure 4.

Although there is illustrated and described herein specific structure and details of operation, it is to be understood that these descriptions are exemplary and that alternative embodiments and equivalents may be readily made by those skilled in the art without departing from the spirit and the scope of this invention. Accordingly, the invention is intended to embrace all such alternatives and equivalents that fall within the spirit and scope of the appended claims.